ABSTRACT

The Thunderbolt Alternate Mode allows the two sides of a USB Type-C™ PD connection to discover, negotiate, and enter the Intel Thunderbolt 3 mode allowing transfer of high-speed data. The mode is negotiated using USB Power Delivery messaging, as listed in the USB PD specification. This application report explains the standard implementation of the Thunderbolt Alternate Mode and how it can be used with the Texas Instruments TPS6598x family of USB Type-C and USB PD controllers and associated software tools.

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1 Introduction

Thunderbolt Alternate Mode support in TPS6598x firmware uses the standard USB Type-C PD alternate mode discovery and negotiation process to control entry to the alternate mode. Discovery and negotiation are performed after USB Type-C analog detection and USB PD power negotiation. Upon entry to the mode, the firmware configures the TPS6598x internal hardware to support high-speed data transfers using the Intel Thunderbolt protocol. Specifically, cable flip (orientation) information is used to configure the hardware. TPS6598x does not perform any Thunderbolt communications; it only configures TPS6598x internal hardware to provide the signaling path. The Intel Thunderbolt controllers in the system are responsible for all Thunderbolt communications. See the Thunderbolt specification from Intel for details.

2 Thunderbolt Alternate Mode Constant Values

Standard USB PD Alternate Mode messaging is used for discovery and negotiation of the Intel Thunderbolt Alternate Mode. Table 1 lists the two hard-coded values used in the messaging.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
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<tbody>
<tr>
<td>Intel SVID</td>
<td>0x8087</td>
</tr>
<tr>
<td>Thunderbolt Mode</td>
<td>0x0001</td>
</tr>
</tbody>
</table>

TPS6598x firmware will use the values in Table 1 when it generates messages containing either the Intel SVID and/or Thunderbolt mode value. The firmware requires its PD partner to use the same values.

3 Thunderbolt Alternate Mode Entry Requirements

The downward-facing port (DFP) controls the discovery, negotiation, and entry of the Thunderbolt Alternate Mode. To enter the mode, both sides of the PD connection must indicate they support Thunderbolt mode of the Intel SVID (see the values in Table 1). But, the cable also must indicate that it can support high-speed signaling used during Thunderbolt Alternate Mode.

The DFP will query the cable using SOP’ messaging during the Thunderbolt Alternate Mode discovery process. Only cables with electronic markers can respond to queries. If the cable does not respond, Thunderbolt mode will not be entered. For Thunderbolt entry the cable must:

- Indicate that it supports USB3.1 Gen1/Gen2 in the USB SuperSpeed Signaling Support field of the cable Discover Identity Command ACK message
- Indicate that it supports USB 3.1 Gen1/Gen2 in the USB SuperSpeed Signaling Support field of the cable Discover Identity Command ACK message and indicate that it supports Intel Thunderbolt mode with the Discovers SVIDs and Discover Modes queries as done on the cable.
Thunderbolt Alternate Mode Host Interface Registers

The following TPS6598x registers support Thunderbolt Alternate Mode:

- **Configuration registers**
  - 0x52, Intel VID Configuration
  - 0x38, Alternate Mode Entry Queue

- **Status registers**
  - 0x59, Intel VID Status

- **Runtime registers**
  - 0x16, Interrupt Mask Register 1
  - 0x5F, Data Status
  - 0x50, Data Control Register

### 4.1 Thunderbolt Alternate Mode Configuration Registers

The primary registers for configuring Thunderbolt Alternate Mode are the Intel VID Configuration register, 0x52, and the Alternate Mode Entry Queue register, 0x38.

#### 4.1.1 Intel VID Configuration Register

The Intel VID Configuration register, Figure 1, is used to enable the Intel VID and enable Thunderbolt mode. A brief description of each parameter in the register follows.

- **Intel VID Config Set**
  - Enable Intel VID – This parameter must be set to allow the Intel SVID to be included in the alternate mode discovery process.
  - Enable Intel Thunderbolt Mode – This parameter must be set to allow the Thunderbolt mode of the Intel SVID to be included in the alternate mode discovery process.
  - Thunderbolt Vout 3V3 Required – This parameter must be set for proper operation of the ResetZ signal. The “Lock 3V3 Output” in the Miscellaneous Configuration register and the “Vout3V3 enable” in the System Configuration register must also be set for proper Thunderbolt operations.
  - Thunderbolt Emarker Override – When this parameter is set, it allows entry to Thunderbolt mode with a cable not meeting Thunderbolt mode entry requirements.
  - AN Minimum Power Required – The bit is used only when acting as a power sink and the request message was sent with capability mismatch set. It causes a VDM attention message, with Intel SVID, to be sent to the host. This message indicates to the host that the sink does not have enough power for Thunderbolt operations. In that case, Thunderbolt Alternate Mode is negotiated and entered as far as the PD partners are concerned, but the host does not truly enter Thunderbolt mode.
  - Thunderbolt Mode Autoentry Allowed – This parameter may be used to allow auto entry of Thunderbolt when all entry conditions have been met. However, this bit is typically not used. Instead, the Thunderbolt mode automatic entry is enabled by including Intel Thunderbolt in the Alternate Mode Entry Queue (see Alternate Mode Entry Queue Register).

**NOTE:** Some TPS6598x devices support more advanced Intel Thunderbolt devices. The Intel VID Configuration Register for those TPS6598x devices includes extra Thunderbolt configuration parameters. Those configuration parameters include the following:

- vPRO capable – This bit should be set when the Thunderbolt device for the port supports Intel vPro mode.
- Dual TBT Retimer Present – This bit should be set when the hardware design includes multiple Thunderbolt retimers. If this bit is set, the following bit should also be set.
- TBT Retimer Present – This bit should be set when the hardware design includes at least one Thunderbolt retimer.
- Data Status HPD Events – This bit should be set when a virtual HPD (hot plug detect) indicator is
desired instead of the default physical HPD indicator. A physical HPD indicator is GPIO signaling. A virtual HPD indicator is performed using a bit in the Data Status register that is read by the Thunderbolt device.

- **Adapter Mode Response**
  - Legacy TBT Adapter – This bit is used only when configuring the firmware to act as a Thunderbolt legacy adapter. A Thunderbolt legacy adapter is a bridge between Thunderbolt 3 and previous generations of Thunderbolt.

- **Cable Mode Response** – The cable mode response fields are used only when the firmware is configured to act as a captive cable Thunderbolt device. The firmware acts as a captive cable when the receptacle type, in the system configuration register, is set to one of the tethered values. Values for the parameters are listed in the Intel Thunderbolt specifications.
  - Cable Speed
  - Cable Generation
  - Cable Type
  - Active Cable
  - Cable Training Supported
    These values are used only when the device responds to SOP’ messages when acting as a captive cable device.

- **Billboard Index**
  - Billboard Index – The billboard index is set to 5 because entry 5 in the string table contains a message about problems with Thunderbolt entry. (See the General Settings tab of the configuration tool for the actual string.)
Figure 1. Intel VID Configuration Register
4.1.2 Alternate Mode Entry Queue Register

The Alternate Mode Entry Queue register (see Figure 2) is used to specify the priorities for entering alternate modes. A brief description of the register follows.

The purpose of the Alternate Mode Entry Queue register is to specify the entry order for mutually exclusive alternate modes. That is, it provides a way to specify the priority for the order of entering alternate modes. And, when any mode in the queue has been entered, no other modes listed in the queue are entered.

For example, both Thunderbolt and DisplayPort alternate modes should not be entered concurrently because Thunderbolt includes DisplayPort. This means that in the typical Thunderbolt firmware configuration, Thunderbolt Alternate Mode entry should have priority over DisplayPort Alternate Mode entry. The register allows listing of up to three modes in priority order. SVID and mode values should be specified in the register for each alternate mode in the entry queue. Unused entries should contain zeroes.

Before any alternate mode is entered, all SVID and mode discovery is performed. Then, the Alternate Mode Entry Queue is used to determine which mode should be entered first. If the mode specified for the first entry queue record is found in the discovery process, that mode is entered and no further entry queue records are processed. If the mode for the first entry queue record is not found in the discovery process, the second record is processed. This process is repeated for the third record, if needed. When an entry queue record matches a discovered SVID/mode, that alternate mode is entered and no further processing of the entry queue is performed.

After processing of the entry queue is complete, the individual autoentry allowed bits in the configuration registers for all alternate modes are processed. Because of this, the autoentry allowed bits for the alternate modes specified in the entry queue are not usually set. The typical configuration only includes Thunderbolt and DisplayPort modes in the entry queue.

Figure 2 shows how the register is populated to give Thunderbolt, 0x8087/00000001, priority over DisplayPort, 0xFF01/00000001. If DisplayPort priority is desired, the entries should be reversed.
4.2 Thunderbolt Alternate Mode Status Registers

If desired, the EC may monitor the status of the Thunderbolt Alternate Mode by reading the contents of the Intel VID Status register, register address 0x59.

4.3 Thunderbolt Alternate Mode Runtime Registers

The Intel Thunderbolt controller (Alpine Ridge is the initial Thunderbolt 3 controller) needs interrupts and data to support Thunderbolt operations. To get this information the controller is connected to an TPS6598X I2C interface 1 (I2C_SCL1, I2C_SDA1, or I2C_IRQ1Z).
5 Interaction With the Thunderbolt Controller

The Thunderbolt controller must receive updates to the data status register, 0x5F. To enable this, the firmware configuration must have the Data Status Update and Plug Event interrupts enabled in the Interrupt Mask Register 1. When the Thunderbolt controller receives the interrupt, it reads the Data Status register. Instead of clearing the interrupts by writing to the interrupt clear register, the Thunderbolt controller writes to the Data Control register, 0x50.

The Thunderbolt controller has inputs for two interrupt signals. This means that when the Thunderbolt controller inputs are connected to two single-port PD controllers (TPS65982, for example), the interrupt signals for both PD controllers are connected to the two Thunderbolt interrupt inputs.

However, when a dual-PD controller (TPS65988, for example) is connected to the Thunderbolt controller, the single interrupt output signal of the PD controller must be connected to both interrupt inputs of the Thunderbolt controller.

6 Thunderbolt Alternate Mode Example

The TPS6598x Configuration Tool contains projects that can be used as the starting point for a typical Thunderbolt Host (laptop) or Source (dock) design. These projects contain all settings required to configure the firmware to enable Thunderbolt Alternate Mode.

NOTE: A tool specifically made for TPS65983 exists. It contains projects explicitly for Intel Thunderbolt reference designs.

The following PD traces were collected with using a Teledyne LeCroy PD analyzer between two TPS65982 EVMs. The “left” EVM in the trace used the binary image created with the example template TPS65982_Thunderbolt_DRP_Source_Standard_3_05.tpl. This configuration is typical for a Thunderbolt dock. It prefers to be the power source and is agnostic about the data connection. The “right” EVM in the trace used the binary image created with the example template TPS65982_Thunderbolt_DRP_Host_Standard_3_05.tpl. This configuration is typical for a Thunderbolt laptop. It is agnostic about being the power source (or sink) and prefers to be the data source. When these two configurations are connected, the left EVM becomes the power source and acts as the UFP for data. The right EVM becomes the power sink and acts as the DFP for data.

The PD specification stipulates that the DFP is in charge of alternate mode discovery and negotiations. This means the right EVM will handle alternate mode entry. But, entry to Thunderbolt mode is dependent on responses from the cable.

In a normal setup there is one Type-C PD cable between the two ports. However, when a PD analyzer is used, two cables must be used. Two Thunderbolt-capable cables are not required. If only one Thunderbolt-capable cable is used, its placement in the test setup is important. For an emarked cable to respond, it must be powered with Vconn. The LeCroy does not pass through Vconn. This means that the Thunderbolt cable must be connected to an EVM that can provide Vconn. For example, if you are testing with your DFP starting in dead battery mode, it cannot provide power to the cable. This means the Thunderbolt-capable emarked cable must be connected between the powered UFP and the LeCroy.

To illustrate the importance of the cable, examples of non-emarked cable, marked cable with no Thunderbolt support indicated, and a full Thunderbolt-capable cable are shown. Only PD messaging relevant to alternate mode entry is shown. For compactness, other PD messaging, including the good-CRC responses, is not shown.

6.1 Non-emarked Cable Example

Upon initial connection, the source first queries the cable to discover identity information using SOP’ PD messaging. A non-emarked cable cannot respond to the discovery request. The lack of a response for a non-emarked cable is shown in PD packets 16 to 19 of Figure 3.
Power contract negotiations and data role negotiations are performed after the initial cable identity query. They have been omitted for compactness.

The next set of communications between the ports is related to alternate mode discovery, as shown in Figure 4.

Alternate mode discovery is controlled by the DFP. The DFP first discovers the identity of the UFP, and then the SVIDs it supports. The PD messages for this are shown in packets 50 to 54 of Figure 4.

NOTE: “Good CRC” responses to each message are not shown.

In this example the DFP supports the Intel (0x8087), DisplayPort (0xFF01), and Texas Instruments (0x0451).

For each supported SVID, the DFP then discovers the modes supported for each SVID. The supported SVIDs and their corresponding mode discovery packets follow.

- Intel SVID – packets 56 to 58
- DisplayPort SVID – packets 60 to 62
- Texas Instruments SVID – packets 64 to 66

Because entry to Thunderbolt Alternate Mode requires a cable capable of supporting high-speed data, the DFP will try to read the cable identity and capabilities using SOPPD messaging. Packets 68 to 147 of Figure 5 show that the non-emarked cable does not respond.

Even through Thunderbolt Alternate Mode was given priority over DisplayPort in the Alternate Mode Entry Queue register (see Alternate Mode Entry Queue Register), we cannot enter Thunderbolt Alternate Mode because we did not get responses from the cable indicating that it can support Thunderbolt speed signaling. This means entry to Thunderbolt Alternate Mode is not shown in Figure 6.
6.2 *emarked, Non-Thunderbolt Cable Example*

Upon initial connection, the source will first query the cable to discover identity information using SOP'PD messaging. An emarked, non-Thunderbolt, cable will respond with its identity. A typical response is shown in PD packets 40 to 42 of Figure 7.

*Figure 7. Initial Cable Query of emarked (Non-Thunderbolt) Cable*

The cable response includes more information than what is shown in Figure 7. Figure 8 shows some of the additional information.

*Figure 8. Cable Capabilities in Initial Query Response*

Note the USB SS field. This is the USB SuperSpeed Signaling Support bits. In this example, the cable supports USB 3.1 Gen 1 (up to 5 GHz) and Gen 2 (up to 10 GHz). This information will be used later.

Power contract negotiations and data role negotiations are performed after the initial cable identity query. Then, communications related to alternate mode discovery are performed. These communications are identical to what is shown in Figure 4.

Entry to Thunderbolt Alternate Mode requires a cable that can support high-speed data. The USB SuperSpeed Signaling Support bits must indicate that the cable supports USB 3.1 Gen 1 or higher. This means that the cable responses to the initial query indicate that the cable is Thunderbolt-capable. However, the cable may also be emarked to indicate it has Thunderbolt certification. An additional cable query will be performed to determine if the cable has this certification. This query is shown in PD packets 101 to 103 of Figure 9.
Certification is determined by checking to see if the cable supports the Intel SVID. Because this example is for an emarked, non-Thunderbolt cable, the Intel SVID is not part of the cable response.

Even though the cable does not have Thunderbolt certification, we are allowed to enter Thunderbolt Alternate Mode based on its SuperSpeed signaling support capability. Figure 10 shows entry into Thunderbolt (Intel) and Texas Instruments alternate modes.

DisplayPort Alternate Mode is not entered because of the entries in the alternate mode entry queue register that indicate Thunderbolt and DisplayPort are mutually exclusive.

Note the additional VDO in packet 105 that commands Thunderbolt mode entry. The data in this VDO is used to tell the Intel system devices in the system information about the cable. The Intel devices read this information from the PD controller using host interface commands. The data in this example corresponds to a cable indicating that it supports USB 3.1 Gen 1 and Gen 2 signaling but does not have Thunderbolt certification.

6.3 Thunderbolt Cable Example

Initial cable discovery, power contract negotiations, data role negotiations, and alternate mode discovery for a Thunderbolt cable is identical to an emarked, non-Thunderbolt cable. The first messaging difference is when the cable queried to determine if it has Thunderbolt certification. Figure 9 shows how a non-Thunderbolt cable responds to the certification query. Figure 11 shows the certification query for a Thunderbolt cable.

A Thunderbolt-certified cable responds that it supports Intel SVID when queried, as shown in PD packet 66. When the DFP finds the cable that supports Intel SVID, it then requests what Intel mode is supported. This mode value is actually information about the cable capabilities. The VDO in PD packet 70 shows the cable capabilities for the Thunderbolt-certified cable used in this example.

Thunderbolt and Texas Instruments alternate modes are now entered, as shown in Figure 12. The cable capability information read from the cable is used when entering Thunderbolt mode, as shown in PD packet 72.
Figure 12. Alternate Mode Entry, Thunderbolt Cable
## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

<table>
<thead>
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<th>Changes from Original (December 2017) to A Revision</th>
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</tr>
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<tbody>
<tr>
<td>• Changed all to allow in Enable Intel Thunderbolt Mode bullet in Intel VID Config Set in Section 4.1.1</td>
<td>3</td>
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<tr>
<td>• Added Note for Advanced Intel Thunderbolt Devices and four bullets to Intel VID Config Set, in Section 4.1.1</td>
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